The MRN-NEEM Model: Integrated Energy-Economy Analysis for Design of California Climate Policy

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Paul Bernstein
David Montgomery

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Outline of Presentation

- Background on CRA and MRN-NEEM
- What kind of a model is needed to inform implementation of climate policies
- How MRN-NEEM provides these capabilities

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The Company

- CRA founded in 1985 (headquartered in Boston)
- Over 660 staff globally in wide range of economics and business consulting practices

CRA's Energy & Environment Practice

- 100 professional staff located in North America, Europe, and Asia Pacific
- Expertise in electricity, natural gas, coal, and related environmental concerns
- Specialized expertise in climate policy design and assessing its impacts to companies and the economy

Our energy practice spans economic & environmental regulation, restructuring, privatization, market design, corporate strategy, transaction support, asset valuation, operational optimization, and organizational development.

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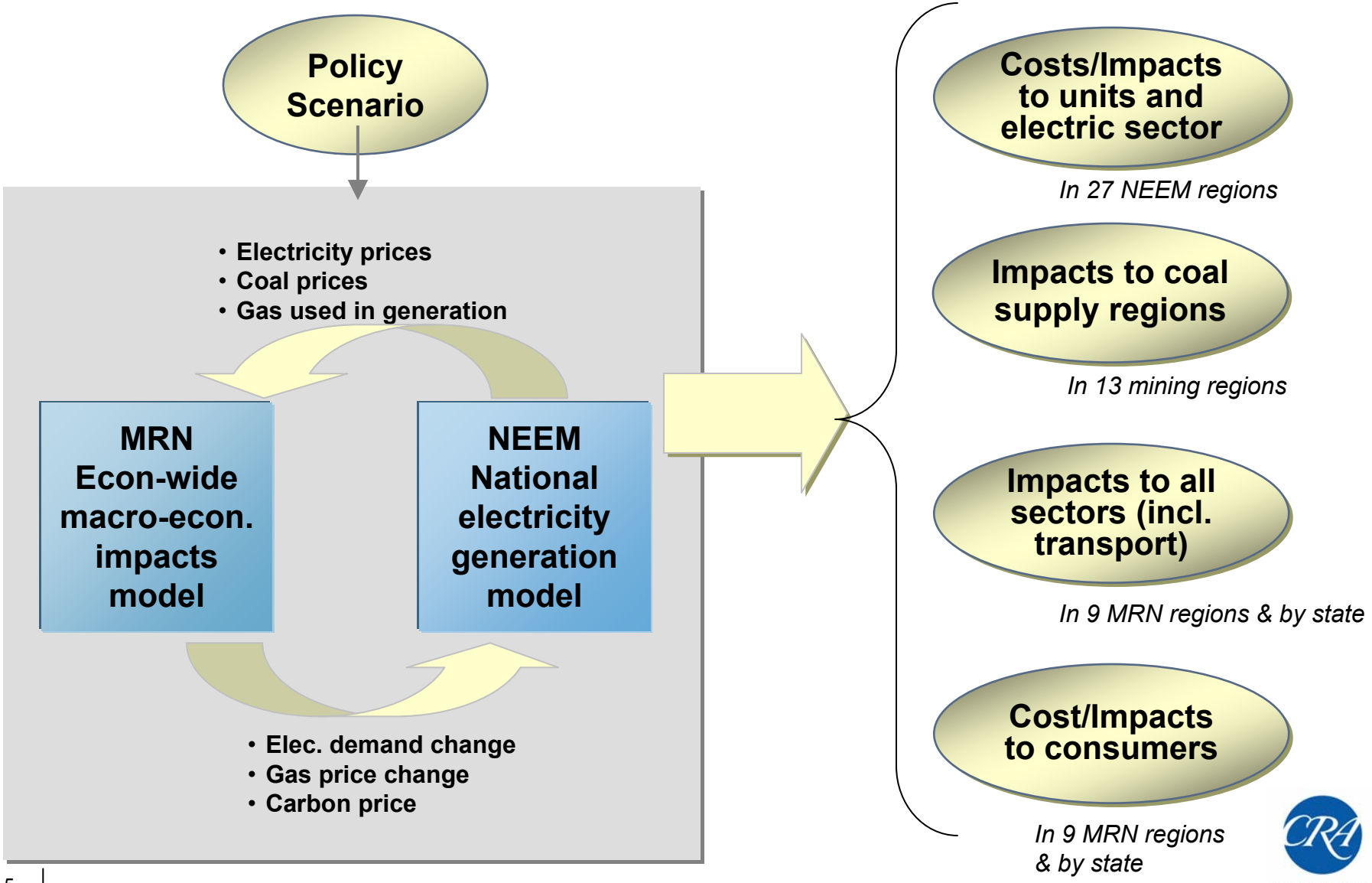
Background on CRA's MRN-NEEM Model Development

- **CRA International is distinguished by providing consulting services based in quantitative analysis**
  - Staff in CRA's Energy and Environment Practice have had a leading role in modeling climate policies since the late 1980s
  - The E&E Practice also provides analytically-based consulting on finance and strategy broadly to energy industries
- **MRN-NEEM combines two of CRA's world-class modeling capabilities**
  - Development over a 15 year period of a system of computable general equilibrium models focused on climate policy issues
  - The culmination of 20 years of development of the most advanced capacity planning and dispatch models for the electricity sector
- **MRN-NEEM was created by leaders in their fields**
  - Professor Thomas Rutherford created the MPSGE modeling language and designed MRN for CRA
  - Dr. Ira Shavel developed the most widely recognized comparable electricity sector models, including the IPM model used by the EPA

Integration of MRN and NEEM Provides a Unique Capability for Analysis of GHG Policy Impacts



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CRA Is Completing A Major Study of California's Climate Policy Based On MRN-NEEM

- **Study for EPRI will address questions of**
  - Will AB 32 impose a cost on the California economy?
  - How can AB 32 and SB 1368 be implemented to avoid unnecessary costs and unanticipated effects?
- **Status**
  - Analysis completed and in review within EPRI
  - Results will not be discussed until review is complete
- **Most sophisticated modeling of AB 32 yet attempted**
  - Detailed model of electricity capacity expansion and dispatch
  - State of the art economic model of California
- **Concentration on elucidation of issues, such as:**
  - How could energy markets be affected by regulatory design?
  - How large are the economic stakes in getting the design right?
  - How will design of regulations for the electricity sector affect incentives for long term contracting and choice of technology for generation?

To Support Policy Design A Model Must Provide Insights into Changes in Behavior and Market Responses

- **Questions about policy design raised by AB32, SB1368 and EO S-20-06**
  - Broad design choices
  - Details of how the electricity sector will be regulated
- **Capabilities required to compare different policy choices**
  - How incentives are altered and how markets will respond
  - Representation of decisions at a level of detail appropriate for comparison of the proposed policies

California Climate Initiative--Policy Development through EO S-20-06

- **AB 32 – all details of implementation left up to state agencies**
  - A cap on total GHG emissions at 1990 levels to be achieved in 2020
  - Timeline for implementation
  - Requirements for various studies
  - No real direction on content of implementation
- **SB 1368 – a transitional requirement?**
  - Emission performance standard for power purchased under long term contract by IOU's and munis
  - To be put in effect in 2007 and to be reconciled with mandatory caps
- **EO S-20-06 – back to markets?**
  - Responds to ambivalence in AB 32 about use of market based measures
  - Mandates development process for market based measures

Major Choices Are Left Unresolved by Legislation

- **Choice of policy approach**
  - Cap and trade (allocation rule, safety valve, banking, revenue recycling, offsets, linkage with other programs, coverage and sources)
  - Carbon tax
  - Command and control
  - Mixed systems
- **Treatment of emissions associated with electricity imports**
  - Measurement of emissions
  - Ownership shares and long term contracts
  - Contract shuffling
  - IOU's versus Munis
- **Schedule for resolution of policy uncertainties**
  - CEC and PUC emissions performance standard for power imports in 2007
  - ARB plan describing choice of regulatory approach due 1/1/09 but completion of final rulemakings not required until 1/1/11
  - No schedule for post-2020 targets or policies

Open issues in policy development

- Will caps be implemented as stated?
- What will be done after 2020 and when will a decision be made?
- To what extent will emission trading be allowed? Which sectors will fall under the cap? What kind of emission sources will trading cover?
- How will permits be allocated? Will the state take revenues from permit sales? How will they be used?
- Will there be a true safety valve to sets an upper limit on the price of permits?
- Will banking and borrowing of emission permits be allowed?
- What are the implications of linking with other trading systems?
- Will regulatory programs be adopted instead of or in conjunction with cap and trade programs?
- How will the resource mix and emissions from electricity imports be defined?
- How will California LSE's contracts and ownership of out-of-state coal powerplants be regulated?
- Will there be constraints on the use of certain technologies?
- What type of policies will be adopted for non-CO2 sources? Will forestry offsets be allowed?

Questions About Costs and Market Response that Require Answers To Design Efficient Policies

- **How close will the policy design come to equalizing marginal cost of abatement across all decisions that affect greenhouse gas emissions?**
- **How much economic risk does the state face due to**
  - The lack of an effective safety valve or banking and borrowing
  - Uncertainty about the costs and availability of non-CO2 emission reductions
  - Uncertainty about the costs of reducing CO2 emissions
- **How predictable are policy impacts? Are some policy approaches inherently more uncertain than others?**
- **How will regulatory policies interact with market based instruments if both are implemented?**
- **Will rules for imported power have unintended consequences for electricity markets due to differences in emission factors depending on the contractual or ownership relationship?**
  - Contract shuffling to divest ownership and switch new and existing contracts from coal units to lower emission units
  - Abandonment of long term contracts and reliance on spot markets
- **How will restrictions on technology choice (e.g. nuclear or IGCC) affect costs of meeting caps?**
- **Will regulatory uncertainty lead to deferral of investment, especially in power generation?**
- **How much leakage in the form of increased emissions outside California is likely under different policy designs?**
- **How much is at stake in designing efficient policies?**

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What Kind of Modeling Capabilities are Required?

- **Basic features of any computable general equilibrium model:**
  - Household decisions based on consistent ranking of consumption alternatives
  - Business decisions based on maximizing profits subject to a production function
  - Complete accounting for factor inputs so that all costs are accounted for
  - Supply and demand equilibrium that supports efficient use of limited resources unless there are specific market failures represented in the model
- **Detail on decisions and technologies within the model should be sufficient to differentiate the impacts of alternative policy approaches**
  - Detailed representation of the electricity sector since this sector is the subject of the most complex and critical regulatory interventions, especially in the near-term
  - Explicit treatment of key technologies whose availability influences costs of meeting targets, such as nuclear power, CCS, and transportation fuels
- **Sufficiently long time horizon to account fully for effects of policies on investment decisions**
- **Fully dynamic so that agents correctly anticipate future price trends and policy decisions**
- **Sufficient regional and sectoral detail to capture important sectoral and regional interactions and differences**

These Capabilities Are Designed into MRN-NEEM

- **MRN can address**
  - Future market developments based on integrated CO2 and electricity price scenarios
  - Implications of broad policy choices for the California economy including risks of unexpected costs
  - Design of “market-based measures and mandates”
  - Relative cost and interactions of market-based and regulatory approaches
  - Treatment of non-CO2 greenhouse gases and other offsets
  - Linkage to other trading systems
- **NEEM addresses critical questions for regulation of the electricity sector**
  - Regulatory uncertainty and capacity investment
  - Demand for long term contracts and spot market purchases
  - Leakage and the cost of electricity
  - Contract shuffling
  - How units will be dispatched under different carbon accounting rules
  - Differences between IOU’s and Munis
  - Transmission costs and constraints
  - Full costs of renewables – intermittency, capacity credits, system stability
  - Availability of technologies and limits on resources

MRN Overview

- **Development**
  - One of a set of CGE models developed at CRA
  - Current CRA team: Tom Rutherford, Paul Bernstein, Sugandha Tuladhar, David Montgomery, Anne Smith
- **MRN data**
  - New IMPLAN data including 2002 input-output matrices and trade flow data
  - EIA state-level energy production, consumption and price data
  - Capability of analyzing California in relation to U.S. economy and energy markets
- **Key economic mechanisms included in MRN model**
  - Possibility of premature retirement of capital
  - Impacts on government budgets, tax interaction and “double dividend” effects
  - Improvement in technology over time or in response to policies with appropriate backstop assumptions to represent technology breakthroughs
  - Sufficiently long time horizon to capture anticipation of future policies
- **Linkage to NEEM**
  - Replaced typical CES representation of electricity production function with a detailed electric power sector model in order to analyze policies that affect electricity transmission and the choice and location of generation
  - Iteration between models to obtain consistent solutions for prices and quantities

Multi-Region National (MRN) Model

- **Classic intertemporal general equilibrium model with consistent point expectations**
  - All agents take market prices in all time periods as given
  - Consumers are endowed with primary factors (labor, capital and an energy resource)
  - Consumers maximize an intertemporal utility function subject to an intertemporal budget constraint
  - Firms plan investment and production to maximize the PV of profits subject to their production function
  - Energy use by existing capital cannot be changed
  - All time periods are solved simultaneously for intertemporally consistent prices
  - Beyond horizon impacts approximated through valuation of the terminal capital stock
- **Multi-region trade model with Armington assumptions**
  - One representative consumer in each region
  - Crude oil and electricity are treated in some respects as homogenous goods
  - All other goods are differentiated by region where produced
  - Trade in goods takes place through a national market for differentiated goods
  - Prices of internationally traded goods move with reference price path
- **Carbon accounting and emission trading are built into MRN**
  - CO2 emissions calculated using emission factors applied to fuel use
  - Emission permits form part of endowment and a market linked to fuel use

Current Features of MRN Relevant to Modeling CAP

- **Incorporates most recent energy and economic data**
  - Updated the database to IMPLAN 2002 based on NAICS classification
  - Improved the dataset "buildstream" to incorporate EIA's latest energy dataset
- **Improved empirical basis for tax representation**
  - Existing Federal and State level marginal and average labor and capital rates
  - Maintenance of government budget balance through adjustment of average tax rates
  - Consistency between marginal and average tax rates and observed revenue flows
- **Explicit treatment of generalized fuel backstop**
  - We have considered only transportation fuel backstop
  - New, zero-carbon transportation fuel appears in response to carbon price raising cost of conventional fuels
- **Possibility of premature retirement of existing capital made uneconomic by policy**
- **Sufficiently long time horizon to capture effects of anticipated future policies**
- **Efficiency and distributional effects of allowance allocations**
  - Options to allocate permits or revenues to households, Federal or State government
- **Electricity sector in MRN is a detailed process model of capacity planning and generation**
  - Top down model (MRN) to model the Non-Electric sectors
  - Bottom-up model (NEEM) to model the detailed Electricity sector

MRN Regional Coverage

50 States & DC

9 Regions

Name	Region	States included
NED	New England States	ME, NH, VT, MA, CT, RI
MDA	Mid-Atlantic States	NY, PA, NJ, MD, DE, DC
RSE	Rest of South East	MS, AL, TN, GA, SC, VA, NC, FL
WSC	West South Central	TX, OK, AR, LA
NWC	North West Central	ND, SD, NE, KS, MN, IA, MO
ENC	East North Central	WI, MI, IL, IN, OH, KY, WV
MOU	Mountain	ID, MT, WY, CO, NV, UT, AZ, NM
PAC	Pacific	WA, OR, AK, HI
CAL	California	CA

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MRN Sectoral Coverage

* Energy Sectors
  - 1 COL Coal
  - 2 CRU Natural Gas and Crude
  - 3 ELE Electric Generation
  - 4 GAS Natural Gas Distribution
  - 5 OIL Refined Petroleum
* General Sectors
  - 6 AGR Agriculture
  - 7 CNS Construction
  - 8 DWE Owner-occupied dwellings
  - 9 MIN Metal and Nonmetal Mining
  - 10 M_V Motor Vehicles -- SIC 371
  - 11 SRV Services
  - 12 TRN Transportation Services
* MECS Energy Sectors
  - 13 ALU Aluminum
  - 14 CHM Chemicals
  - 15 COM Computer and Electronic Products
  - 16 ELQ Electrical Equipment and Appliances
  - 17 FAB Fabricated Metal Products
  - 18 FOO Food and Kindred Products
  - 19 I_S Iron and Steel
  - 20 MAC Machinery
  - 21 MSC Miscellaneous Manufacturing
  - 22 OPM Other Primary Metals
  - 23 PAP Paper and Pulp Mills
  - 24 PRN Printing and Related Support
  - 25 RUB Plastics and Rubber
  - 26 SCG Nonmetallic Mineral Products
  - 27 TEX Textiles and Apparel and Leather
  - 28 TRQ Transportation Equipment
  - 29 WOO Wood Products and Furniture

10 Industrial Sectors

* Energy Sectors

- 1 COL Coal Production
- 2 CRU Crude Oil
- 3 ELE Electricity Generation
- 4 GAS Natural Gas Distribution
- 5 OIL Refined Petroleum Products

* Non-Energy Sectors

- 6 AGR Agriculture
- 7 EIS Energy Intensive Sectors
- 8 MAN Manufactured and Processed Goods
- 9 TRN Transportation Services - Commercial
- 10 SRV Services

* Final Demand Sectors

- C Housholds
- G Goverenment
- I Investment

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MRN Inputs Based on Public Macroeconomic Data

- **Input-output tables of US economy at state level from IMPLAN**
- **EIA data on energy flows and prices**
- **Tax rate and revenue data from National Bureau of Economic Research's TAXSIM model**
- **EIA forecasts of energy prices and quantities (AEO)**

CRA corrects IMPLAN's regional economic data to make them usable for energy analysis

Raw IMPLAN data are inconsistent with energy quantities and prices reported by EIA

CRA modifies the IMPLAN energy accounts to match EIA's state-level energy data

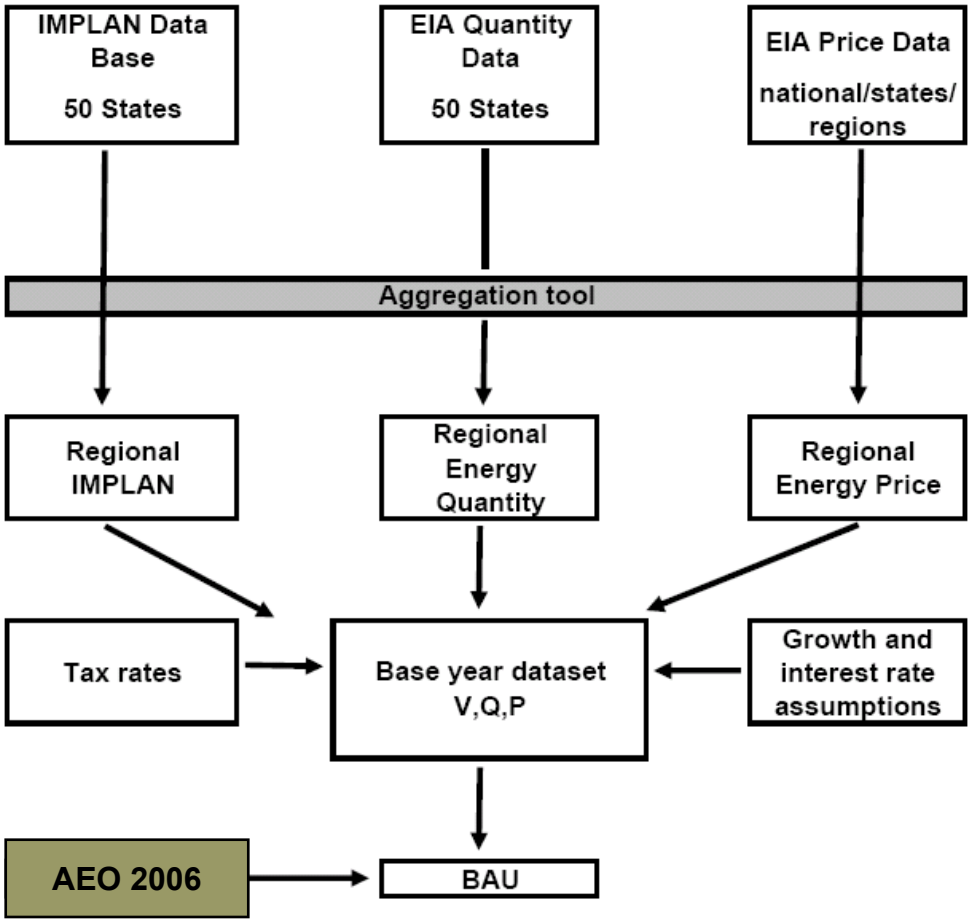
IMPLAN-Energy Dataset for MRN

- **CRA maintains a close relationship with IMPLAN**
  - CRA has developed datasets derived for IMPLAN (U.S.) and GTAP (International) that reconcile economic accounts with accepted energy data
  - Professor Rutherford provides a set of "Tools for Building National Economic Models Using State-Level IMPLAN Social Accounts" at http://www.mpsge.org/implan98.htm
- **IMPLAN 2002 dataset was merged with EIA energy data to produce a consistent energy-economic dataset**
  - IMPLAN 2002 not suitable to analyze energy policy because the energy representation is incomplete and inconsistent with energy quantities and prices reported by EIA
  - A dataset that correctly represents the energy sectors at the state level is required
  - We replace the energy values of the IMPLAN energy accounts to match the implicit energy values derived using EIA's state-level energy data to generate an economic-energy dataset.
  - We perform a least-squares procedure on economic-energy dataset to ensure that the resulting IMPLAN-Energy dataset is balanced

Representation of Federal and State Level Tax Data In MRN Model

- **Four different tax rates incorporated into the MRN model:**
  - Federal marginal and average tax rates on labor income
  - Federal marginal and average tax rates on capital income
  - State marginal and average tax rates on labor income
  - State marginal and average tax rates on capital income
- **The tax rates are based on the marginal and average tax rates used in the NBER's TAXSIM model**
- **Federal and state excise taxes on energy are included as part of IMPLAN-EIA database**
- **Inclusion of existing taxes on income and energy make it possible to**
  - Properly estimate the excess burden of policies that layer additional explicit or implicit taxes on top of existing taxes
  - Address the potential "double dividend" effects of using revenues from carbon taxes or auction revenues to reduce distorting taxes
  - Make a connection between effects of climate policies on state budgets and their effects on overall economic performance

MRN Dataset Development Process



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Key Parameter Assumptions

Annual benchmark growth rate	3.0%
annual benchmark depreciation rate	5.0%
Annual benchmark interest rate	5.0%
Depreciation elasticity	0.3
Intertemporal elasticity of substitution	0.5

	Short Run	Long Run
Coal supply elasticity	0.4	1.9
Crude supply elasticity	0.3	1.0
Natural Gas supply elasticity	0.6	1.0

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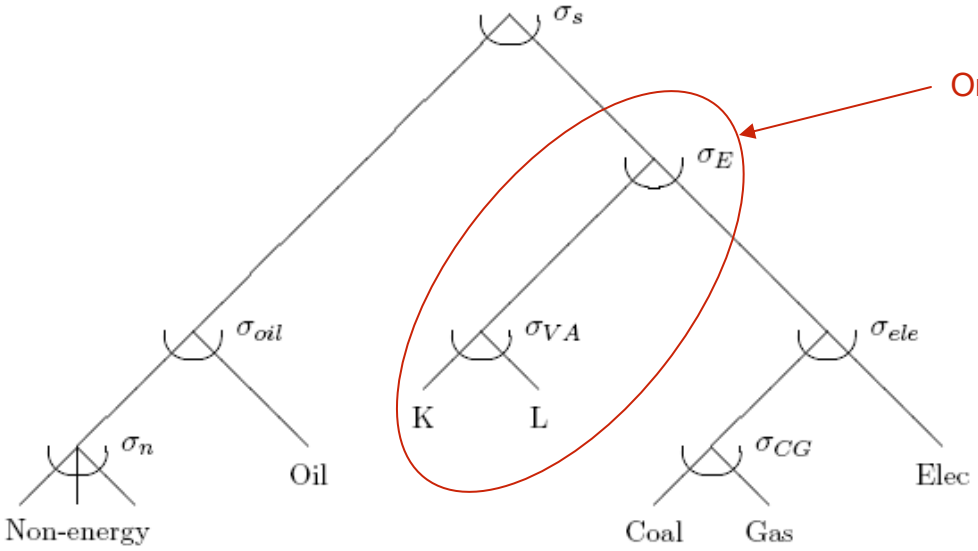
Demand Structure Central Elasticity Assumptions



	Description	Industry*	Final Demand
σ_s	Top-level energy and non-energy	0.0	0.5
σ_n	Non-energy inputs	0.0	1.0
σ_{cg}	Coal and natural gas	0.5	0.5
σ_{va}	Value-added	0.8	na
σ_{ele}	Electric and non-electric energy	0.8	0.5
σ_E	Energy	0.5	na
σ_{oil}	Oil (transport fuel)	0.4	0.4

* excludes Electric sector

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Typical MRN Outputs

- **Welfare change (Hicksian Equivalent Variation)**
- **Carbon**
  - Total emissions
  - Carbon price
- **Macroeconomic**
  - Consumption
  - Investment
  - GDP
  - Wages
  - Real consumption per household
  - Employment
- **Sectoral**
  - Output by region
  - Prices by region
  - Employment by region
- **Energy (Crude oil, refined products, natural gas, coal and electricity)**
  - Wellhead (and ex-refinery prices) by region
  - Delivered prices by sector and region
  - Quantity produced by region
  - Quantity consumed by region
- **Government Budget**
  - Required tax change to maintain budget balance
- **Trade**
  - Terms of trade with other regions and abroad
  - Imports and exports
  - Capital flows

NEEM

- **CRA's North American Electricity and Environment Model (NEEM) is designed to model:**
  - Decisions about the timing and mix of new generating capacity
  - Retirement and mothball decisions
  - Environmental compliance decisions for SOx, NOx and Hg including pollution control retrofits and choice of emission controls for new units
  - Fuel choice in new units and fuel switching in existing units
  - Dispatch decisions (20 period load duration curve)
- **NEEM models the US electric power system and portions of the Canadian system**
  - Fundamental geographical structure is determined by transmission interfaces - 28 NERC regions/sub-regions
  - Additional geographic structure within regions to reflect environmental regulations, usually along state boundaries
  - Operates over a 45 year time horizon matching MRN
- **NEEM is one of the leading electric power models nationwide**
  - Designed by Ira Shavel, who also created the IPM model used by EPA for similar purposes
  - NEEM, IPM and NEMS have been accepted as the most comprehensive modeling frameworks for analysis of impacts of 3P and 4P regulations on the power sector
  - NEEM has capabilities and features beyond those of other models

Major Outputs of NEEM

- **Environmental allowance prices**
- **Electricity prices (Total and by component)**
  - Capacity prices
  - Energy prices
  - Cost of meeting RPS
- **Coal prices by coal type**
- **New capacity and retirements**
- **Generation by unit**
- **Environmental retrofits**
- **Fuel consumption**
- **Electricity demand**
- **Transmission between power pools**

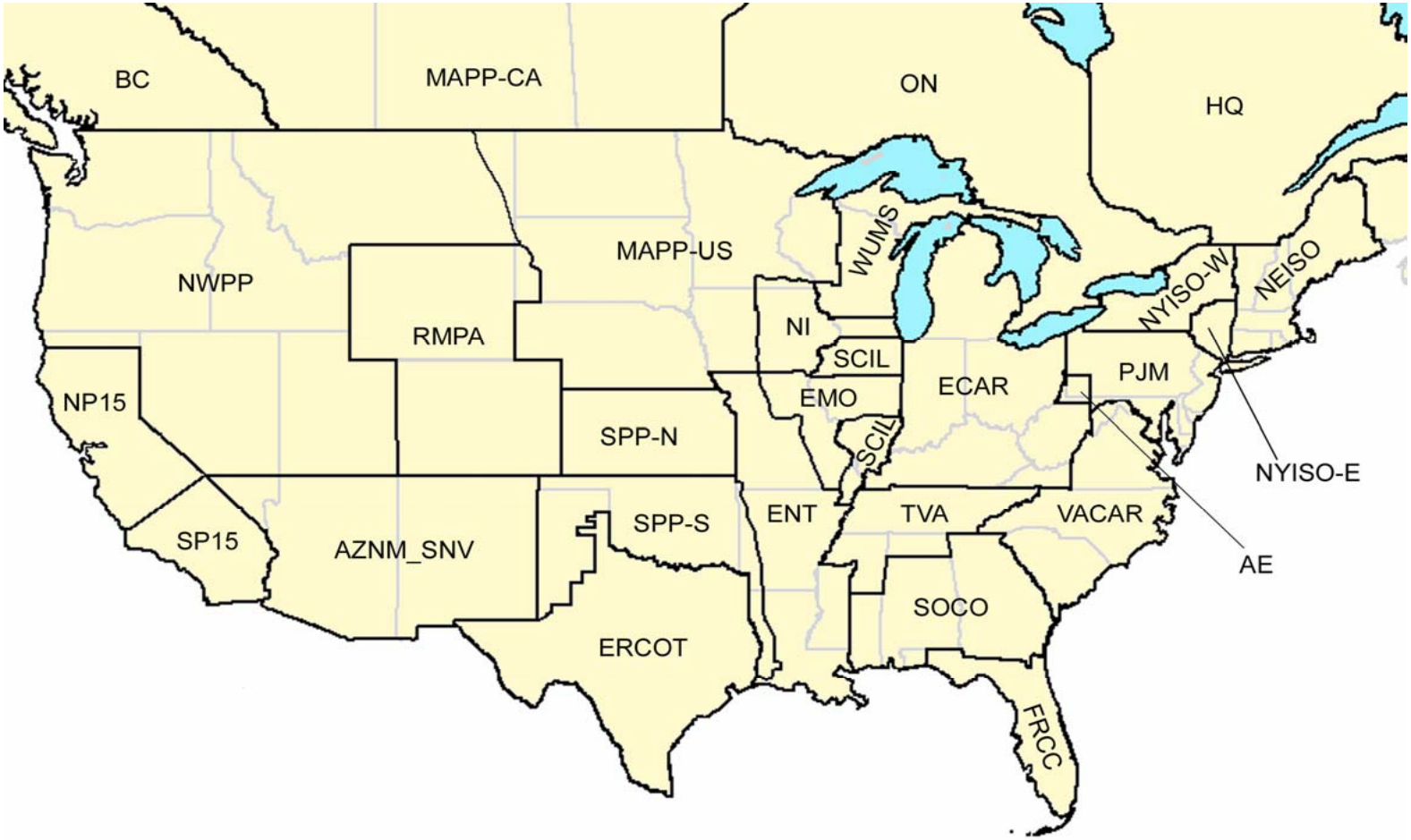
NEEM is a QP Optimization

- **NEEM is solved by maximizing consumer and producer surplus**
  - Unlike other electric sector models that minimize cost of meeting specified demand, NEEM includes an electricity demand curve and supply curves for natural gas and coal
  - Maximizing consumer and producer surplus computed as the area between the electricity demand curve and the total cost of generation finds the competitive market equilibrium
  - Demand and supply curves are updated by iterating with MRN to obtain a consistent solution
- **Generation cost includes**
  - Building new capacity
  - Retirements
  - Environmental compliance
  - System dispatch (All operating costs –fixed and variable O&M and fuel)
  - Transmission
- **Constraints in NEEM ensure that:**
  - Electricity demand is met
  - Reserve margin requirements are met
  - Environmental constraints are satisfied
  - Unit operational limits and energy limits cannot be exceeded
  - Limits on interregional power flows cannot be exceeded (transmission constraints)
  - Unit maintenance requirements are met
  - RPS standards are met
- **NEEM is written in GAMS and uses the QP solver MOSEK**

NEEM Methodology

- **NEEM solves every 5 years from 2010 to 2050**
- **Existing units**
  - Aggregated by region/type, peakers and steam oil/gas also by size and heat rate
  - Most coal plants are modeled at the unit (or same-station, sister-unit) level
  - Small coal units also aggregated
  - Feasible alternative coal supply choices are modeled for each coal plant
  - Database includes long term contracts and ownership shares
- **Load is represented as an Load Duration Curve for each year in each region**
  - Typically 10 slices summer, 5 winter, 5 spring/fall but can be altered
  - LDCs for future years based on 2004 load shapes adjusted for future peak and energy demand

NEEM Transmission Regions



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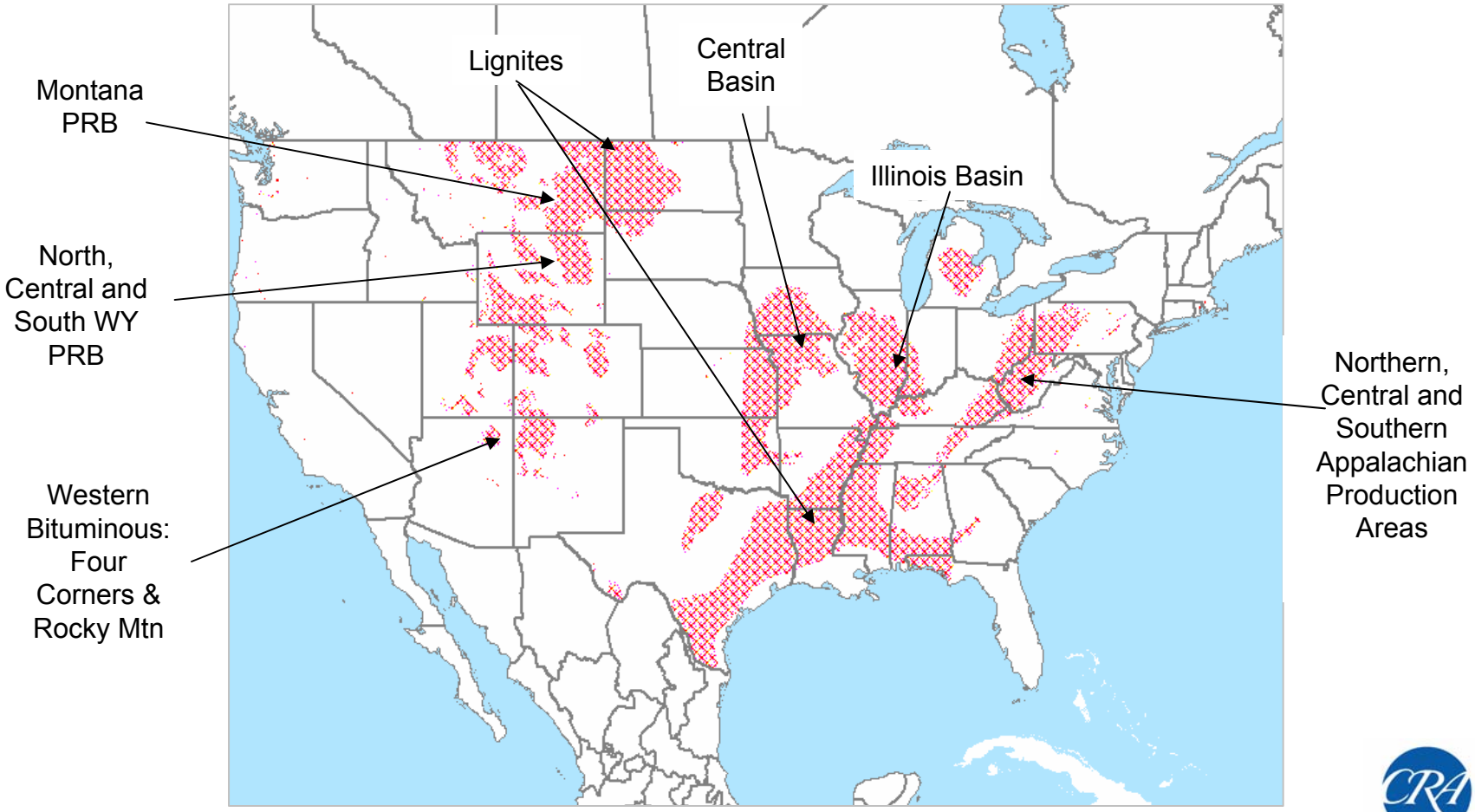
NEEM Has Detailed Representation of US Coal Supply and Transportation Infrastructure

19 individual curves representing distinct domestic production areas, Latin American imports, and different coal qualities (Hg, S, and Btu)



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New Unit Additions & Retirements

- **NEEM adds new units to meet load growth & maintain reserve margin**
  - Can force in “known” new units
  - NEEM has full menu of future units, both fossil fuel and renewable, with capital cost varying by region
  - Can specify renewable resources and potential along with RPS standards by region
  - Can limit type, location, quantity of new units permitted
  - Can specify ownership or long term contracting shares for new units
- **New unit builds – year, type, size, region – are an output of NEEM optimization**
- **Retirements are also a NEEM output, and occur when economically rational**
- **All units are dispatched to meet demand in each load segment subject to transmission and other constraints**

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NEEM Can Represent Any Future Generating Technologies

Technologies Now Included in California Model

	Existing Units	New Units
Fossil Fuel	Oil and gas-fired CTs Gas-fired CCs Oil and gas-fired steam units Coal-fired steam units	Gas-fired CTs Gas-fired CCs Pulverized coal units Integrated gasification CC Integrated gasification CC with sequestration
Nuclear	Nuclear	Advanced Nuclear
Renewables	Wind Geothermal Photovoltaic Solar (thermal) Wood/Refuse Hydro Pumped Storage	Wind Geothermal Photovoltaic Solar (thermal) Biomass Landfill gas

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NEEM Input Data

- **NEEM input data is primarily from public sources**
  - Load forecasts (ES&D, FERC Form 714)
  - Unit data (EIA411, Platts, NERC GADS)
  - Cost and and performance of retrofits (EPRI, EPA)
  - Emission regulations and emission limits (State and Federal rules)
  - Costs of new units (EIA, CRA estimates)
  - Estimates of future renewable energy (ES&D, EIA, CRA estimates)
  - Transmission interfaces (NERC planning documents)
  - Unit emission rates (NERC GADS)
- **Fuel prices are derived from other CRA models and EIA data**

NEEM Schematic

NEEM Inputs

Fuel Prices

- Gas and oil prices from MRN and CRA's Gas Model
- Coal supply curves from the Coal Supply Model

Electricity Demand

- Consistent with MRN

Existing Unit Data

- Fossil
- Nuclear
- Renewable

New Technology Cost and Performance

- New resources (supply-and demand-side)
- Emission control retrofit costs

Environmental Scenarios

- Emission caps
- Carbon tax
- RPS

Transmission

- Limits between regions
- Wheeling charges

NEEM Model

- Maximize consumer plus producer surplus
- 45 year horizon (with end-effect modeling to 2070)
- 20 period load duration curve
- 28 NERC regions/ sub-regions

NEEM Outputs

- Allowance prices
- Wholesale regional on- and off-peak electricity prices
- Coal prices reflecting supply and demand by coal type
- New resources by region
- Retirement/mothball decisions
- Emission control retrofits

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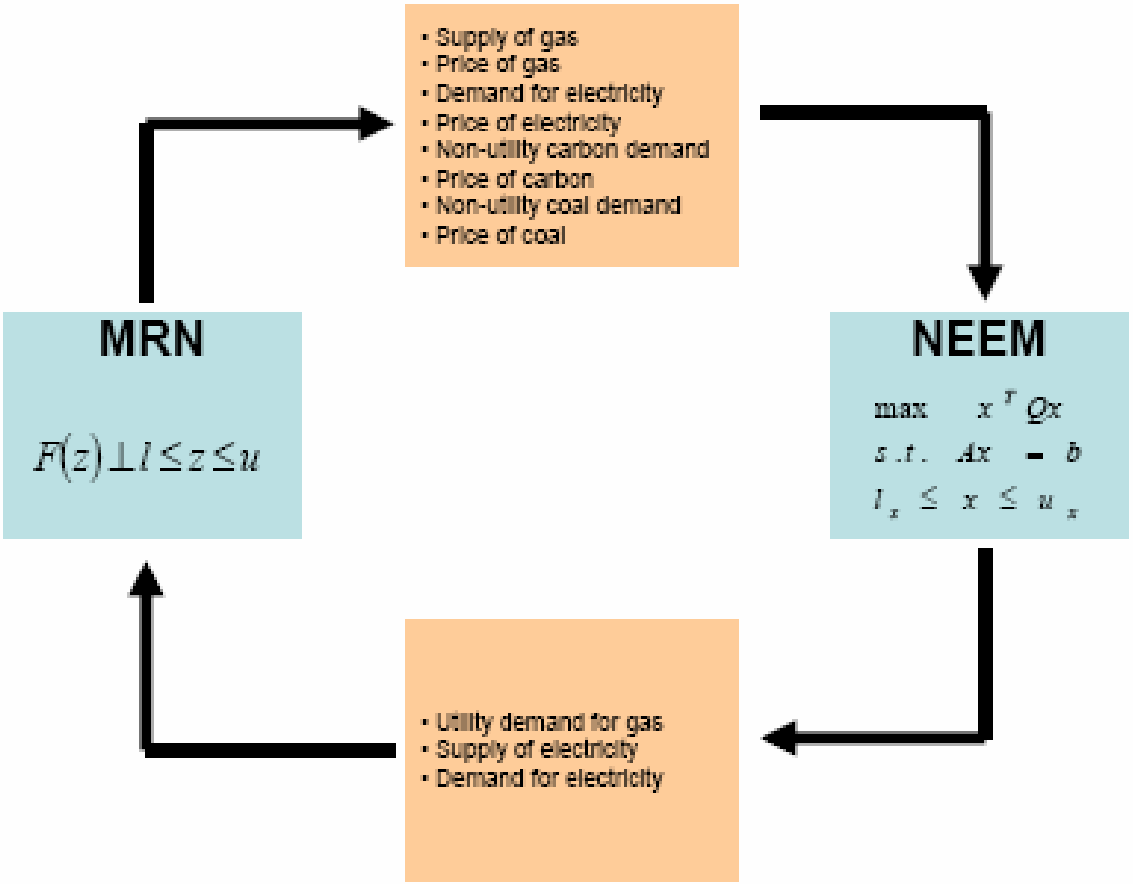
Recap of MRN-NEEM Model Integration



• From MRN: we pass non-utility coal demand, non-utility carbon demand, and a linear approximation to the demand function for electricity and supply function for natural gas
• To MRN: we pass back electricity prices and generation as well as demand for factors of production (fuels, labor, capital, and other inputs to electricity)

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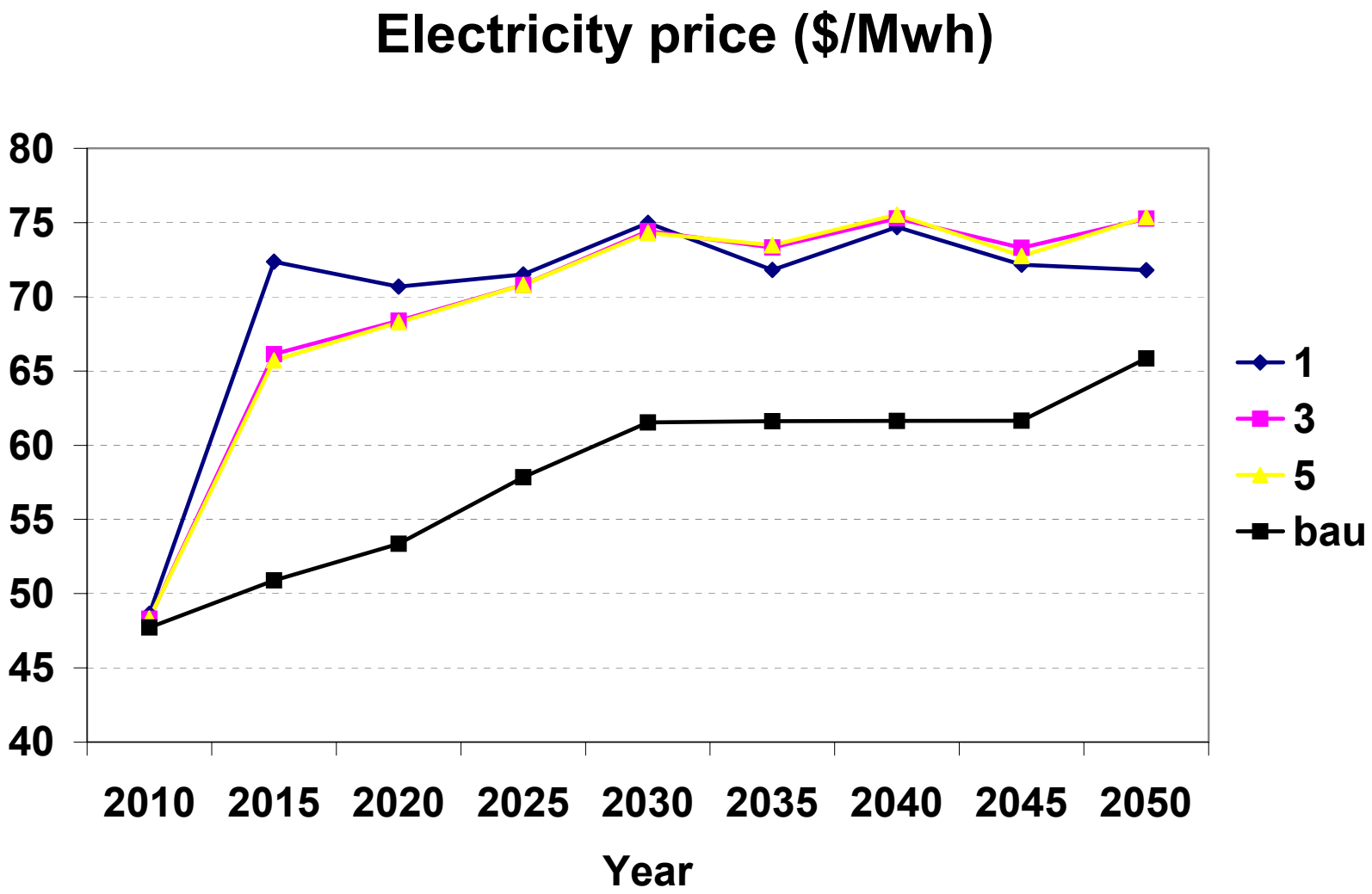
Electricity price convergence in MRN-NEEM Model



These are arbitrary scenarios designed to test convergence and do not represent impacts of California climate policies

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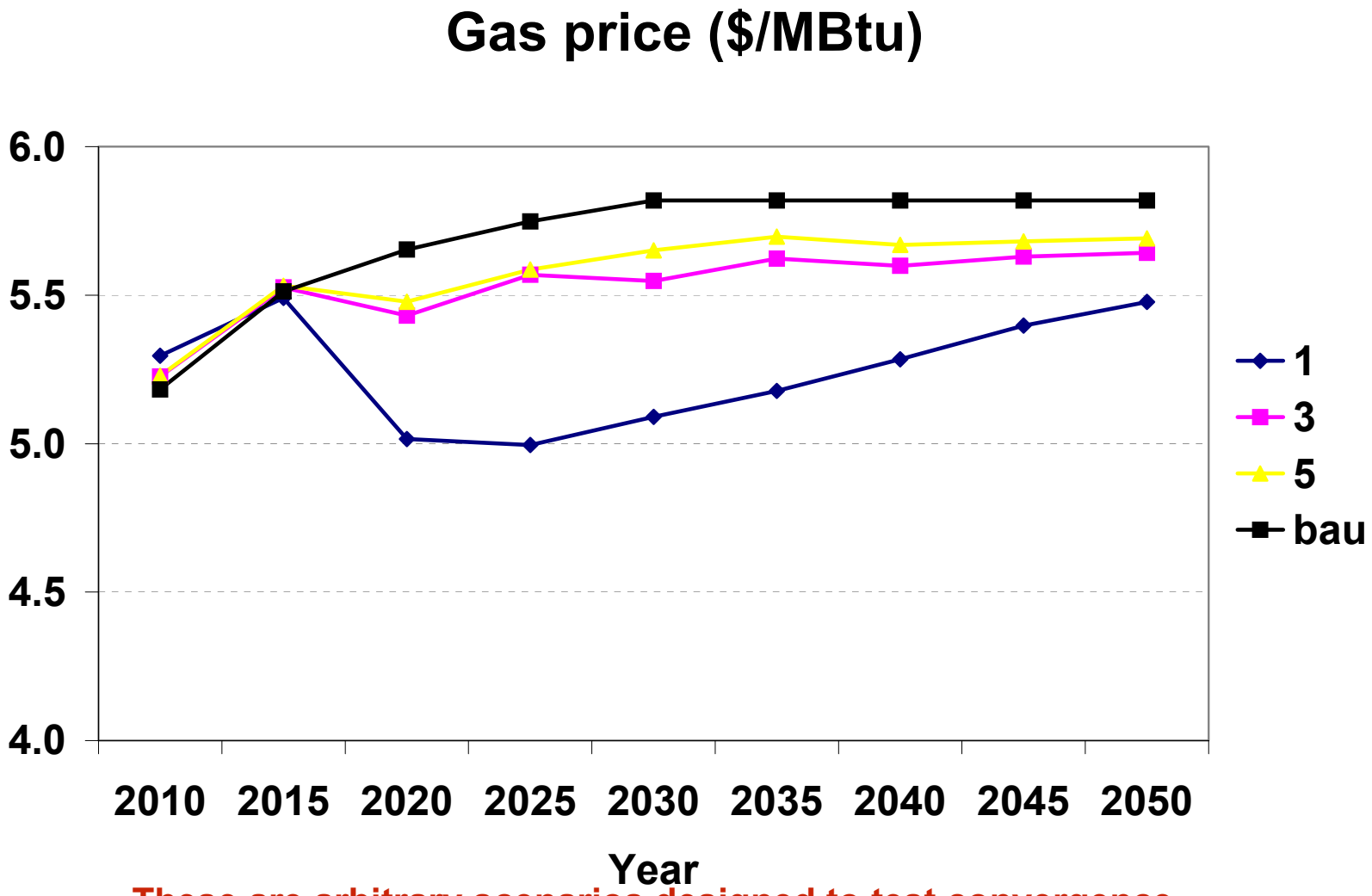
Gas price convergence in MRN-NEEM Model



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